

Plant breeding

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Introduction

- Plant breeding deals with the aspect of crop production
- It is a science based on principles of genetics and Cytogenetics
- It aims at improving the genetic makeup of crop plants
- It consists of principles and the methods required for favorably **changing the genetic constitution of crop plants**
- This usually produces **crop varieties more suited to human needs in one or more aspects than the existing ones**
- Thus continuous favorable changes in the genotype of crop varieties are a must for increasing yields from crop plant as the population in India is growing at an alarming rate. This makes it necessary that the food grain production should also increase at least at the same rate or even faster rate in order to improve the nutritional status and to build self sustainable nation



Objectives of plant breeding

To improve the characteristics of plants so that they become more desirable agronomically and economically

Most breeding programmes aim at higher crop yield and this is achieved by developing more efficient genotypes

Quality is an important aspect for plant breeders

Developing resistant varieties and most convenient method of disease and insect control

Permitting new crop rotations and often extending the crop area

Modifying the agronomic characteristics such as plant height, tillering, branching, erect or trailing habit etc

Development of photoinensitive and temperature insensitive crop varieties

Development of varieties with determinate growth

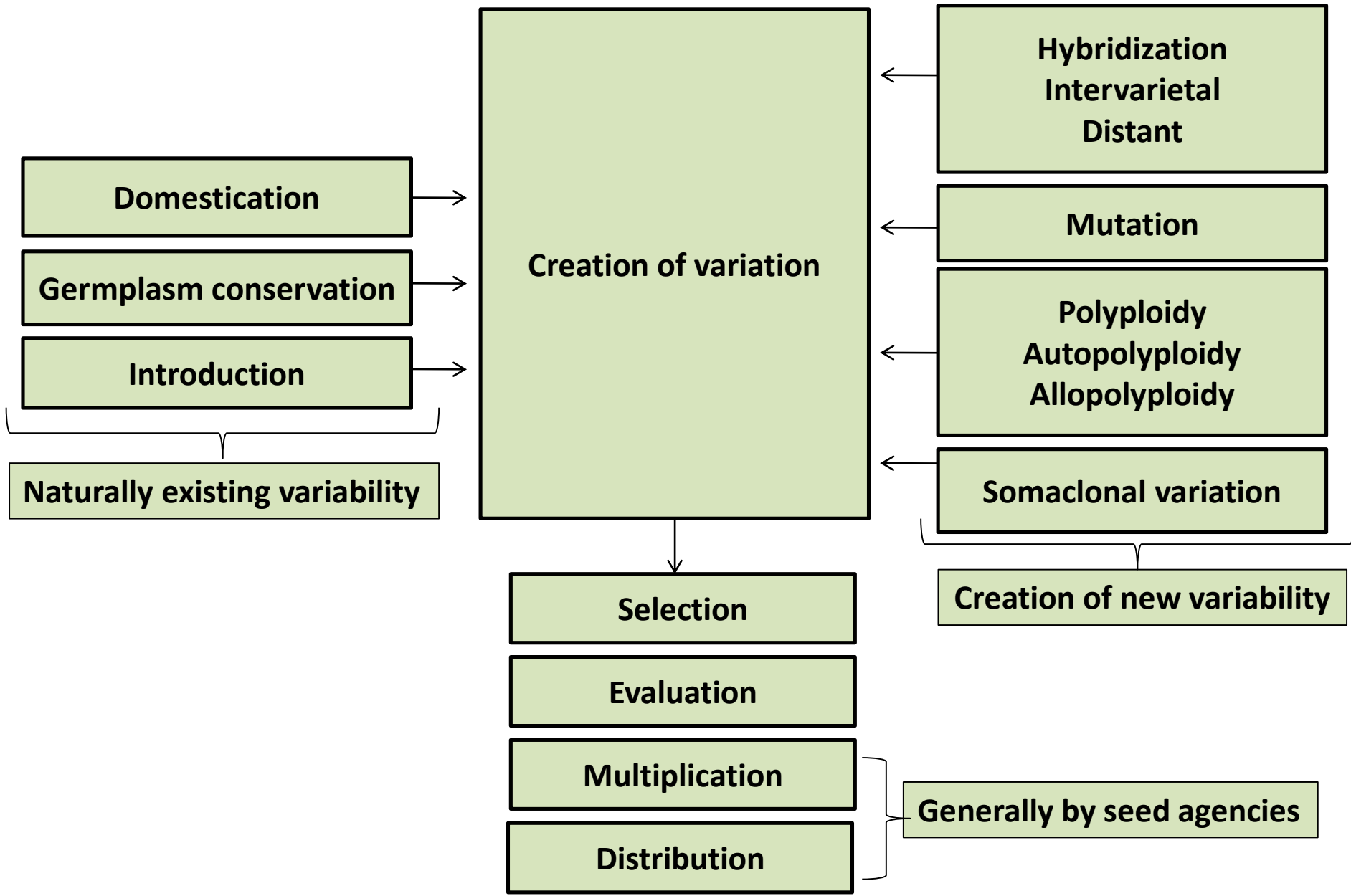
Removing the dormancy in crop seeds and promoting its germination

Developing varieties for new seasons

Development of moisture, stress and salt tolerant crop varieties

Methods to eliminate toxic substances

Activities in plant breeding



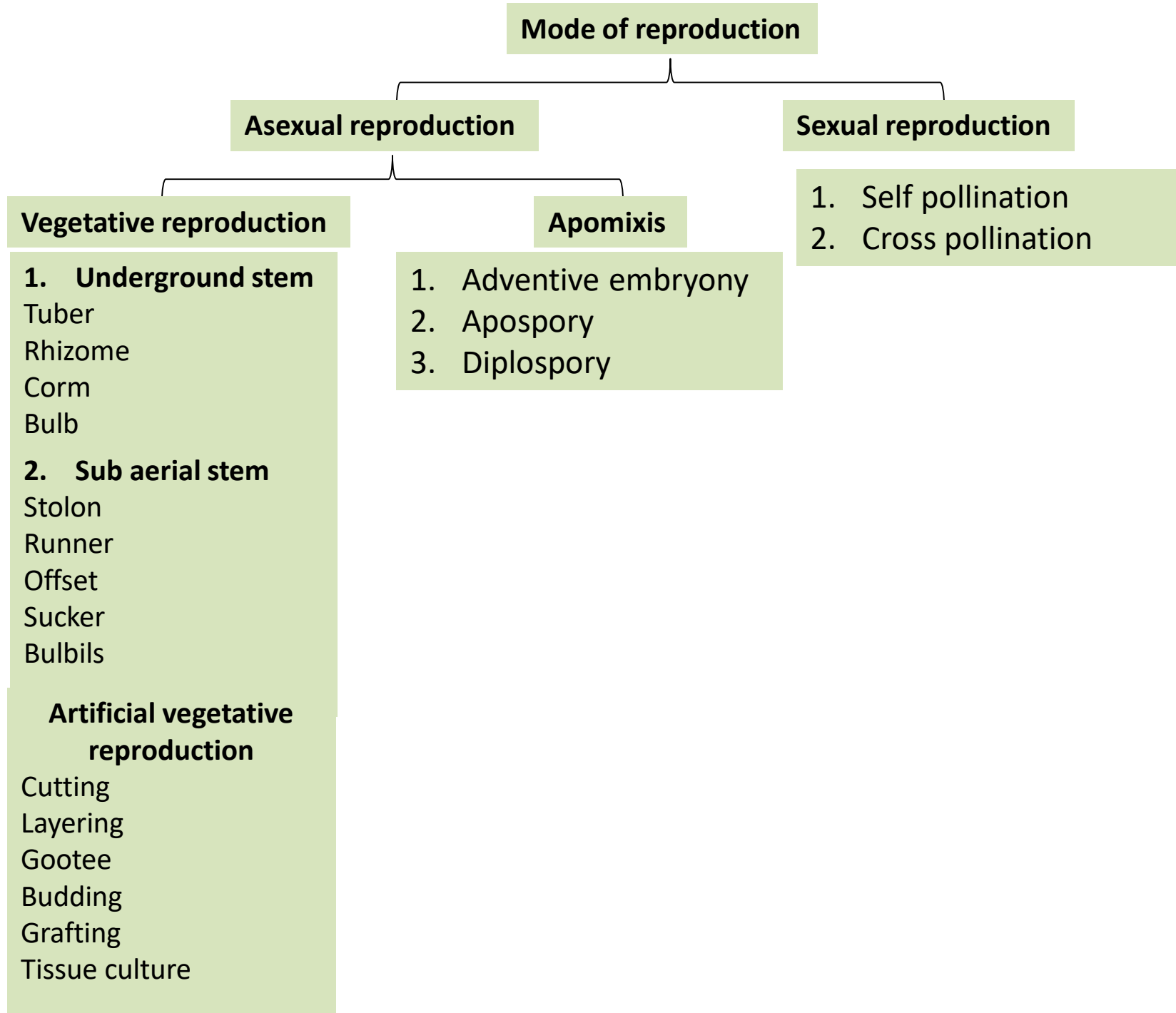
Modes of reproduction in crop plants

Mode of reproduction

- Determines the genetic constitution of crop plants
- That is, whether the plants are normally homozygous or heterozygous
- Determines the goal of the breeding programme

Need of this knowledge:

- If naturally homozygous eg, As in self pollinator like wheat, A homozygous line would be desirable variety
- If naturally heterozygous eg, As in cross pollinators like Maize, A heterozygous population has to be developed as a variety
- Consequently the breeding methods have to be vastly different for the 2 groups of crop plants



Asexual reproduction

- Does not involve fusion of male and female gametes
- New plants may develop from,
- Vegetative parts of the plants (vegetative reproduction) or
- may arise from embryos that develop without fertilization (apomixis)

Vegetative reproduction

- New plant develops from a portion of plant body
- This may occur through modified underground, sub-aerial stems and through bulbils

Underground stem

Underground
modification of stem
serves as storage organs
and contains buds
Buds develop into shoots
and produce plants after
rooting

Tuber
Potato
(*Solanum
tuberosum*)

Bulb
Onion (*Allium
cepa*)
Garlic (*Allium
sativum*)

Rhizome
Ginger (*Zingiber
officinale*)
Turmeric
(*Curcuma
domestica*)

Corm
Bunda (*Colocasia
antiquorum*)
Arvi (*Colocasia
esculenta*)

Sub Aerial stem



Runners



Bulbils



Stolon



Suckers

SIMPLE LAYERING

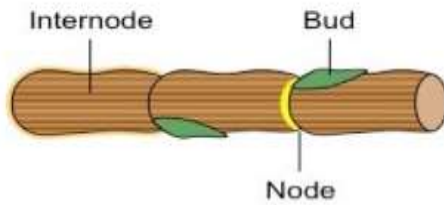


Tissue culture



Gootee

Artificial vegetative reproduction



Stem Cutting



Grafting



Budding

Significance of vegetative propagation

- Species offer unique possibilities in breeding
- A desirable plant may be used as a variety directly regardless of whether it is homozygous or heterozygous
- Mutant buds, branches or seedlings if desirable can be multiplied and directly used as varieties

Apomixis

- In apomixis, seeds are formed but the embryo develop without fertilization
- Plants resulting from them are identical in genotype to the parental plant
- Sexual reproduction is either suppressed or absent
- When sexual reproduction does occur, the apomixis is termed as facultative
- When sexual reproduction is absent, it is referred to as obligate

Apomixis can be further classified into,

Adventive embryony

Embryo develop directly from vegetative cells of ovule, such as nucellus, integument and chalaza
Development of embryo does not involve production of embryo sac
Ex. *Mango, Citrus*

Apospory

Vegetative cells of ovule develop into unreduced embryo sacs after meiosis
Embryo may develop from egg cell or some other cell of this embryo sac
Ex. *Malus, Crepis*

Diplospory

Embryo sac is produced from the megaspore which may be haploid or more generally diploid
Generally meiosis is so modified that megaspore remains diploid
Diplospory leads to,

Parthenogenesis

Embryo develops from egg cell
Based on the nature of embryo sac (haploid or diploid)
Parthenogenesis is classified as,

Apogamy

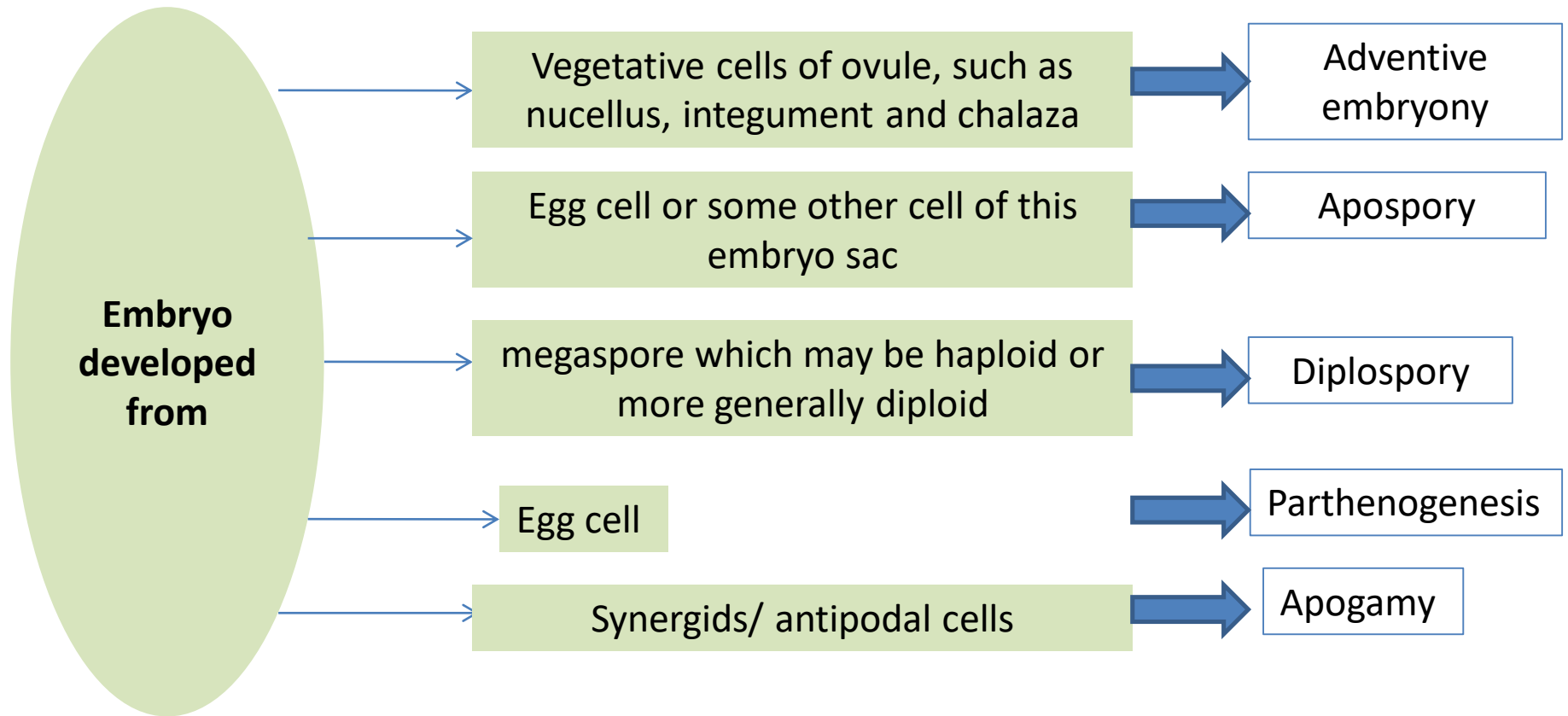
Synergids/ antipodal cells develop into an embryo
May be haploid/ diploid depending upon the haploid or diploid state of embryo sac
Ex. *Antennaria, Allium*

Haploid parthenogenesis

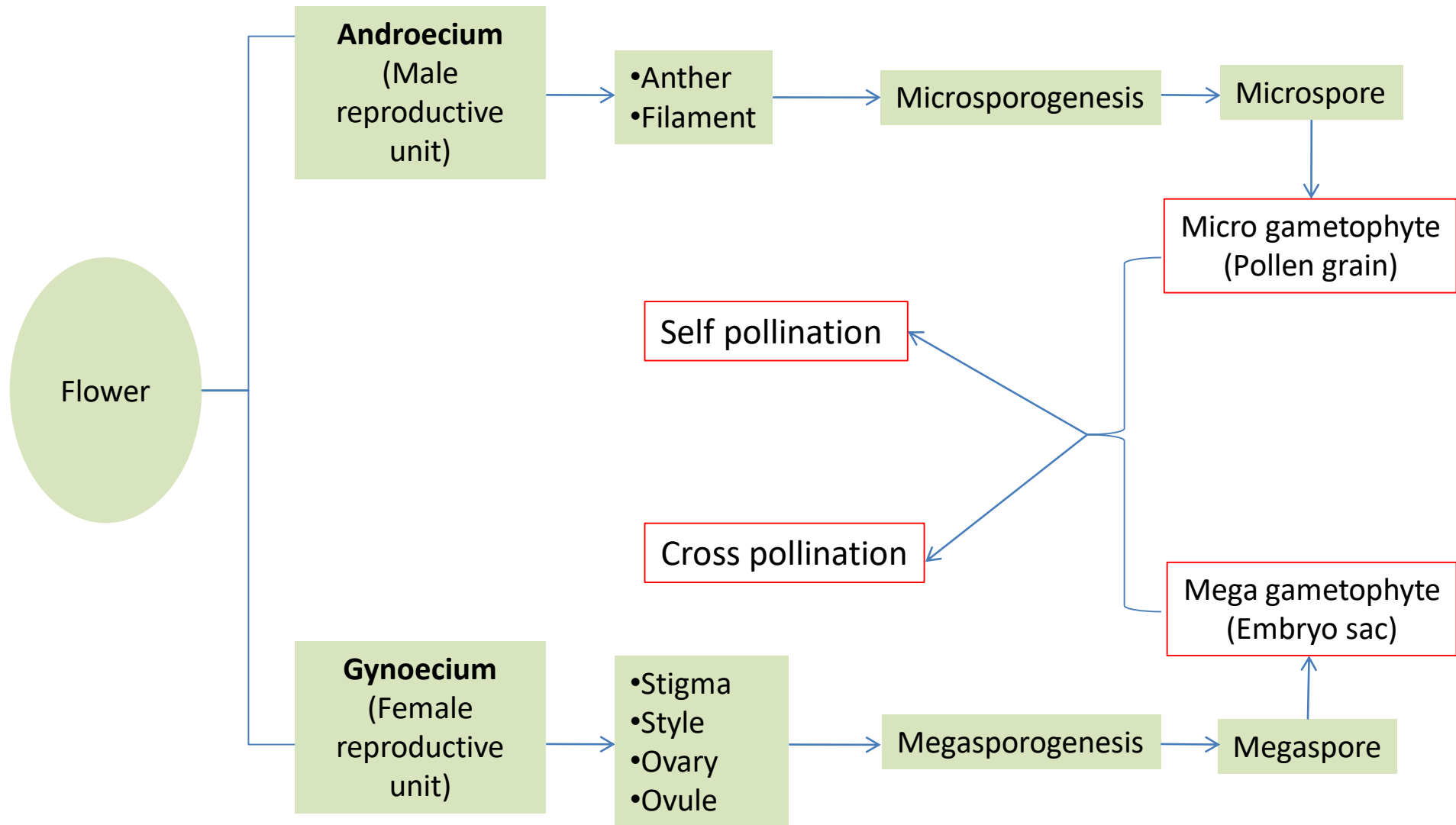
Haploid embryo develops from egg cell
Occurs accidentally
Ex. *Solanum nigrum, Maize*

Diploid parthenogenesis

Diploid embryo develops from egg cell
Ex. Grasses *Taraxacum*



Sexual reproduction



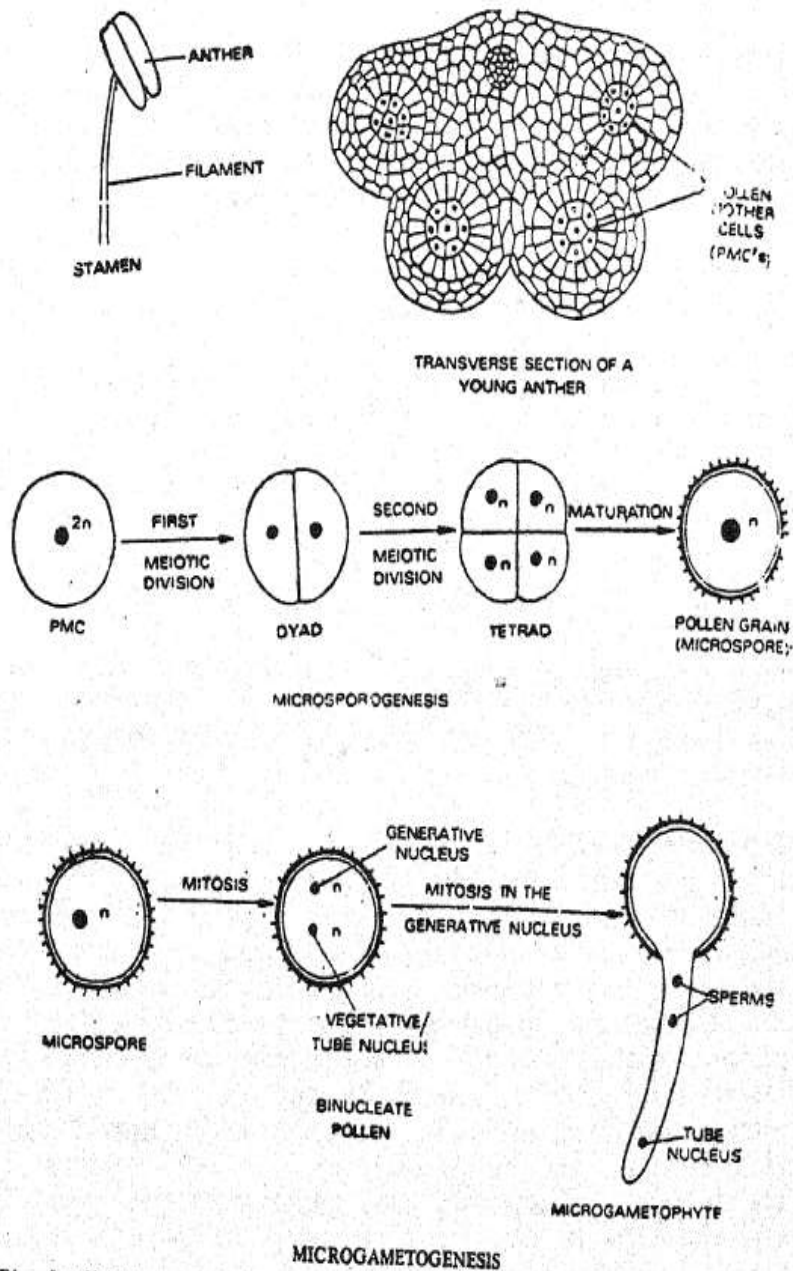


Fig. 3.1. Microsporogenesis and microgametogenesis (a generalised scheme).

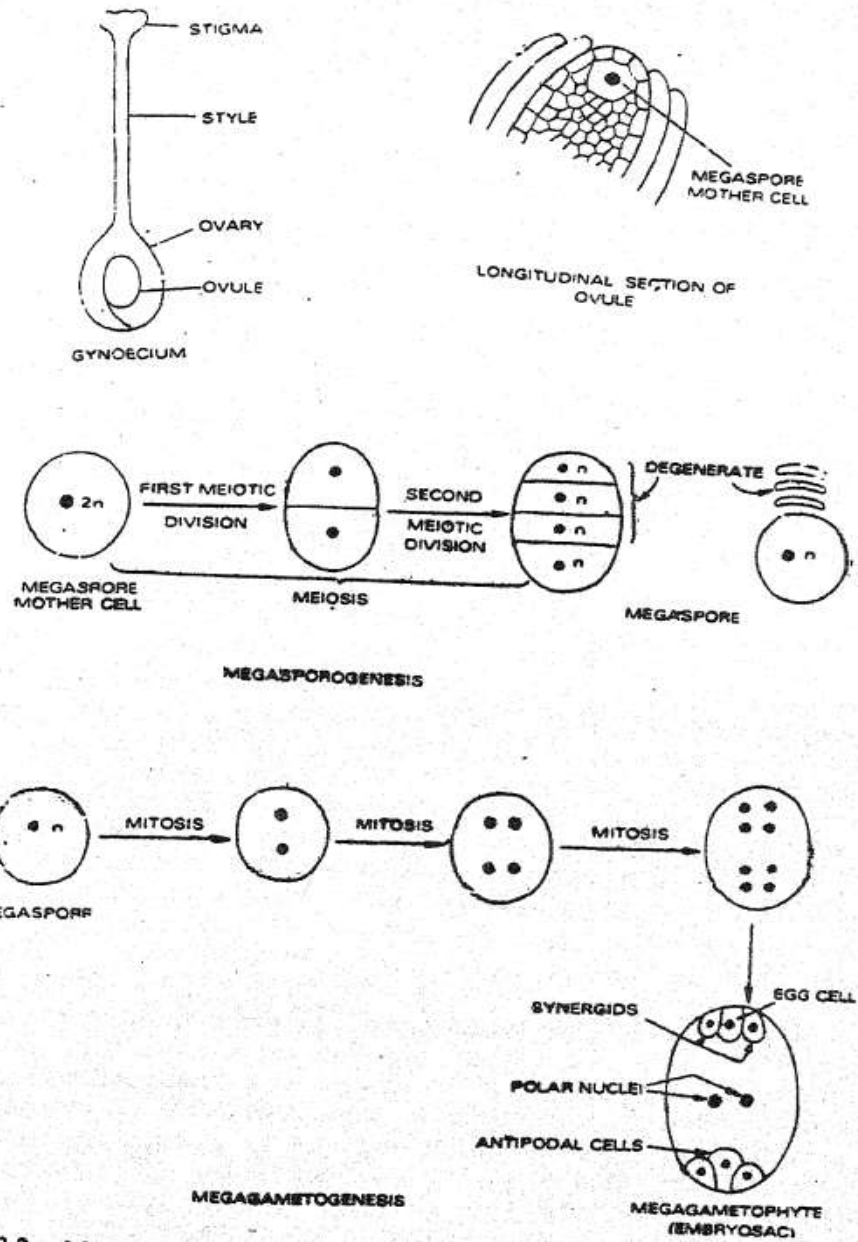


Fig. 3.2. Megasporogenesis and megagametogenesis (a generalised scheme).

Relevance of the mode of reproduction to plant breeding

Determines,

Genetic constitution of a species

Cross pollinated species- highly heterozygous, consists of one (hybrid varieties) or many (open pollinated and synthetic varieties) genotypes show loss in vigour on inbreeding

Self pollinated species- homozygous, a variety consisting of plants of a single genotype, do not show inbreeding depression

Asexual reproduction- similar to cross-pollinated species, can be directly used as a variety

Ease in pollination control

To ensure or prevent selfing largely depend upon floral structure and the mode of pollination of species

In self pollinating crops- selfing occurs naturally

In cross pollinating crops- flowers have to be hand pollinated and protected from foreign pollen

Stability of varieties after release

Self pollinated varieties- fairly stable in their genetic constitution farmers have to take precautionary measures to avoid off-types due to mechanical mixtures

Similar in asexually reproducing species also

Cross pollinated species- sufficient precautions has to be taken to avoid contamination by foreign pollen

Important achievements of plant breeding

Production of semi dwarf cereal varieties

Noblisation of Sugarcane

Development of hybrid maize, jowar, bajra

Commercially exploiting Heterosis in cotton

Introduction of genetically modified Bt cotton

Molecular breeding

Production of semi dwarf cereal varieties:

- **Wheat**

Semi dwarf wheat (*T aestivum*) varieties developed by N E Borlaug and his associates at CIMMYT, Mexico

- These varieties were resistant to rusts and other major diseases of Wheat, fertilizer responsive and high yielding
- This was due to incorporation of resistant genes in their genotype
- This increased and stabilized wheat production in India as well
- These varieties are photoinensitive and many of them are suitable for late planting
- This enabled cultivation of wheat in nontraditional areas like West Bengal

- **Rice**

Semi dwarf rice (*O sativa*) Variety derived from Dee-geo-woo-gen a dwarf, early maturing variety of japonica rice from Taiwan, Taichung native 1 (TNI) developed in Taiwan and IR8, developed at IRRI (International Rice Research Institute), Philippines, were introduced in India in 1966

- Extensively grown
- Replaced by superior semi dwarf varieties (Jaya, Rathna)
- Resistant, fertilizer responsive, high yielding and photoinensitive
- This enabled cultivation of rice in nontraditional areas like Punjab

Noblisation of Sugarcane

C A Barber, T S Venkataraman and others at Sugarcane Breeding Institute, Coimbatore, transferred the thicker stem ,high sugar content and other desirable characters from the noble canes to the Indian canes (*S officinarum* (tropical noble canes) and *S Barberi* (Indian canes)

This is commonly called Noblisation of Indian canes

- They crossed *Saccharum spontaneum*, a wild species to transfer disease resistance and other desirable characteristics to cultivated varieties
- The result of breeding programme was high yielding varieties with high sugar content and well adapted to local climate

Development of hybrid maize, jowar, bajra

Breeding programme in India in collaboration with Rockefeller and Ford Foundations

- Several Ganga series of hybrids were released
- Ex. Ganga Safed 2, Deccan
- Hybrid varieties of Jowar- CSH 1, CSH 2, CSH 3, CSH 4, CSH 5
- Hybrid varieties of Bajra- PHB 10, PHB 14, BJ 104, BK 560
- In Karnataka hybrid varieties occupied large areas
- Composite varieties were also developed to overcome the difficulties encountered with hybrid varieties
- Ex. Manjari, Vikram, Sona, Vijay and Kisan

Commercially exploiting Heterosis in cotton

First hybrid variety of cotton was H4 (a hybrid from 2 *G hirsutum* strains). Developed by Gujarat Agriculture University (Surat station) and released for commercial cultivation in 1970

- Several other hybrid varieties like Jk Hy 1, Godavary, Sugema, H6 and AHH 468, Varalakshmi, CBS 156, Savitri, Jaylakshmi and H2HC were released
- Hybrid varieties were high yielding, had high ginning outturn and good fiber quality
- Occupied 70% of total area under irrigated cotton

Introduction of genetically modified Bt cotton

Bollgard Bt Cotton developed by Mahyco Monsanto Biotech (India) Pvt. Ltd.,

- Bollgard is genetically modified cotton variety that incorporates the Bt gene
- Conferred resistance against bollworm pests
- Helped farmers to reduce insecticide sprays and achieve higher cotton yields

Molecular breeding

- Utilizes molecular biology techniques to achieve plant breeding objectives
- Marker assisted selection (MAS) enables dependable indirect selection for desirable genes using highly reproducible DNA markers
- Ex. Bacterial leaf blight resistant rice varieties improved Pusa Basmati 1 and improved Samba Mahsuri
- Submergence tolerant rice variety- Swarna sub-1
- Improved protein quality maize hybrid- Vivek QPM 9
- Genome sequencing of Rice was published in 2002
- Genome sequencing of pigeon pea genome was published in October 2011
- Enhances efficiency of breeding efforts for improving difficult to select for complex traits
- Marker assisted recurrent selection coupled with off season crops has permit 2 to 3 selection cycles in 1 year as compared to 1 selection cycle in 2-3 years by conventional methods

Undesirable consequences of plant breeding

Reduction in variability among cultivated varieties of a species

Use of similar/ related varieties as parents in breeding programmes

Production of homogeneous varieties than unimproved local and open pollinated varieties

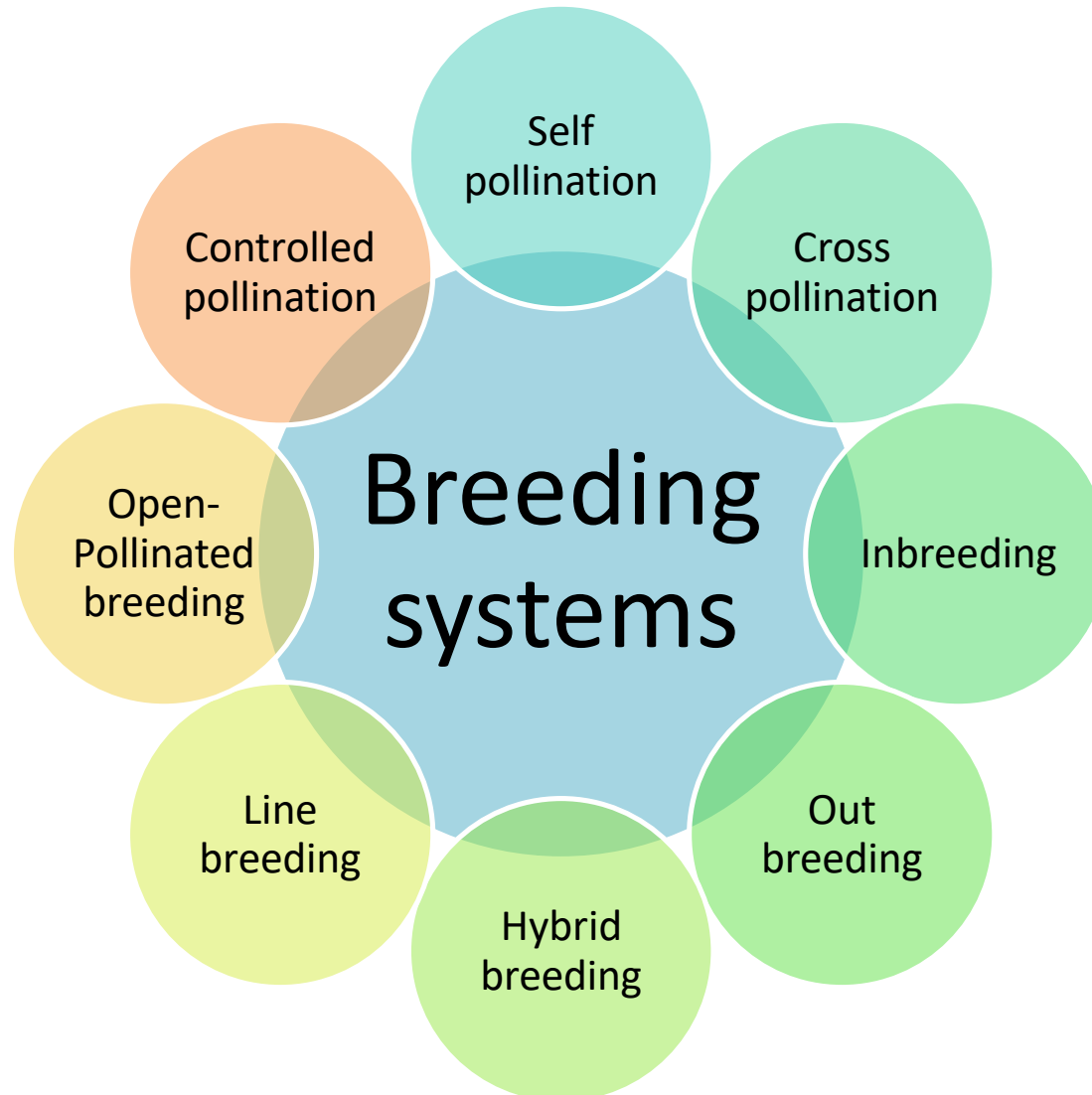
Rapid depletion of genetic variability (genetic erosion)

Narrowing down of the genetic base of varieties (Genetic Vulnerability)

Variability for yield in a crop species is exhausting and no further yield increases are obtained

Breeding systems

Breeding systems refers to the methods and strategies used to control pollination and fertilization





Self pollination

- *Pollen from an anther fuses with stigma of same flower leading to self pollination or Autogamy*
- *It is believed to have originated from cross pollinated ancestors*
- *These species as a rule, must have hermaphrodite flowers*

Various mechanisms to promote self pollination:

- **Cleistogamy**- flowers do not open at all that ensures complete self pollination

Ex. Varieties of wheats (*Triticum* sp.) Oats, Barley and other grasses

- **Chasmogamy**- Flowers open but only after the pollination has taken place

Ex. Cereals such as wheat, barley, rice etc

In crops like Tomato and brinjal the stigma are closely surrounded by anthers. Pollination generally occurs after the flowers open. But the position of anthers in relation to stigmas ensures self pollination

In some species, flowers open but the stamens and the stigma are hidden by other floral organs. In several legumes (Pea, Mung, Urad, Soybean, Gram the stamens and the stigma are enclosed by 2 petals forming keel

In few species, stigma become receptive and elongate through staminal column. This ensures predominant self pollination

Application in plant breeding :

Rapid increase in homozygosity

- Populations of self pollinated species are highly homozygous
- Exhibit considerable Heterosis
- The aim of breeding methods generally is to develop homozygous varieties



Cross pollination

- ***Transfer of pollen form a flower to stigma of other flower***
- ***This may be brought about by air (Anemophily), water (Hydrophily), Insects(Entamophily)***
- ***It is often called Allogamy***

Several mechanisms facilitate cross pollination:

Diclity- Unisexuality is a condition in which the flowers are either staminate (male) or pistillate (female)

- **Monoecy-** staminate and pistillate flowers occur in the same plant, either in the same inflorescence. Eg. Castor, Mango, Banana and Coconut or in separate inflorescences Eg. Maize
- **Dioecy-** Male and female flowers are present on different plants, i.e. the plants in such species are either male / female Eg. Papaya, Date, Hemp, Asparagus, Spinach
- In some cases, there are hermaphrodite plants in addition to males and females and a number of intermediate forms may also occur

Dichogamy- Stamens and pistils of hermaphrodite may mature at different times facilitating cross pollination

- **Protogyny-** In crop species like bajra, pistils mature before stamens
- **Protandry-** In crops like Maize and sugar beets, stamens mature before pistils

Self incompatibility- It refers to failure of pollen from am flower to fertilize the same flower or other flowers on the same plant. 2 types: Sporophytic and Gametophytic

Male sterility- It refers to absence of functional pollen grains in otherwise hermaphrodite flowers. 2 types: Genetic and Cytoplasmic

Application in plant breeding:

- Preserves and promotes heterozygosity in a population
- Cross pollinated species are highly heterozygous and show mild to severe inbreeding depression and a considerable amount of Heterosis
- Breeding methods in such species aim at improving the crop species without reducing heterozygosity to an appreciable degree



Inbreeding

Mating between individuals related by descent or ancestry
The highest degree of inbreeding is achieved by selfing

Effect of inbreeding:

- Increase in homozygosity in the progeny
- Reduction or loss in vigour and fertility
- Reduction in reproductive capacity
- Reduction in size of various plant parts and in yield
- Appearance of lethal and sublethal alleles
- Separation of the population into distinct lines

Application in plant breeding:

- Development of pure lines
- Fixation of desirable traits
- Hybrid breeding
- Seed production
- Breeding for recessive traits



Out
breeding

Also called as outcrossing, refers to breeding between unrelated individuals or lines

Effects on outbreeding:

- Increases genetic diversity
- Increased vigour, yield and disease resistance
- Improved adaptability
- Heterozygosity can be observed
- Genetic variation
- Breaking linkage disequilibrium

Application in plant breeding:

- Hybrid crop production
- population improvement
- Introgression breeding

A diagram showing a large green circle with the text 'Hybrid breeding' inside. Above it, there are smaller circles in blue and green, suggesting a process or components of the breeding process.

Hybrid breeding

Crossing two genetically distinct parent lines to produce offspring with superior traits

Effects of hybrid breeding:

- Hybrid vigour (Heterosis)
- Increased yield
- Improved disease resistance

Genetic consequences of hybrid breeding:

- Heterozygosity
- Genetic diversity

Application in plant breeding:

- Crop improvement
- Hybrid seed production
- Increased food security

A diagram showing a large green circle with the text "Line breeding" inside it. The circle is partially overlapping with other colored shapes (yellow, blue, green) in the top left corner.

Line breeding

Breeding plants within a specific lineage or family to concentrate desirable traits. It is used to develop genetically stable and uniform varieties

Effects of line breeding:

- Increased homozygosity
- Genetic uniformity
- Improved trait expression
- Reduced genetic diversity
- Increased inbreeding depression risk
- Fixation of traits

Application in plant breeding

- Variety development
- Trait introgression
- Seed production



Open-Pollinated breeding

It involves allowing plants to pollinate naturally, either by self-pollinated or cross pollination, without controlled pollination

Effects of open-pollinated breeding:

- Genetic diversity
- Adaptation
- Evolution

Genetic consequences of open pollinated breeding:

- Heterozygosity
- Segregation
- Genetic variation

Application in plant breeding:

- Variety development
- Crop improvement
- Conservation



Manually controlling the pollination process to achieve specific breeding objectives

Effects of controlled pollination breeding:

- Precise control the parentage of offspring
- Increased efficiency to accelerate breeding programmes

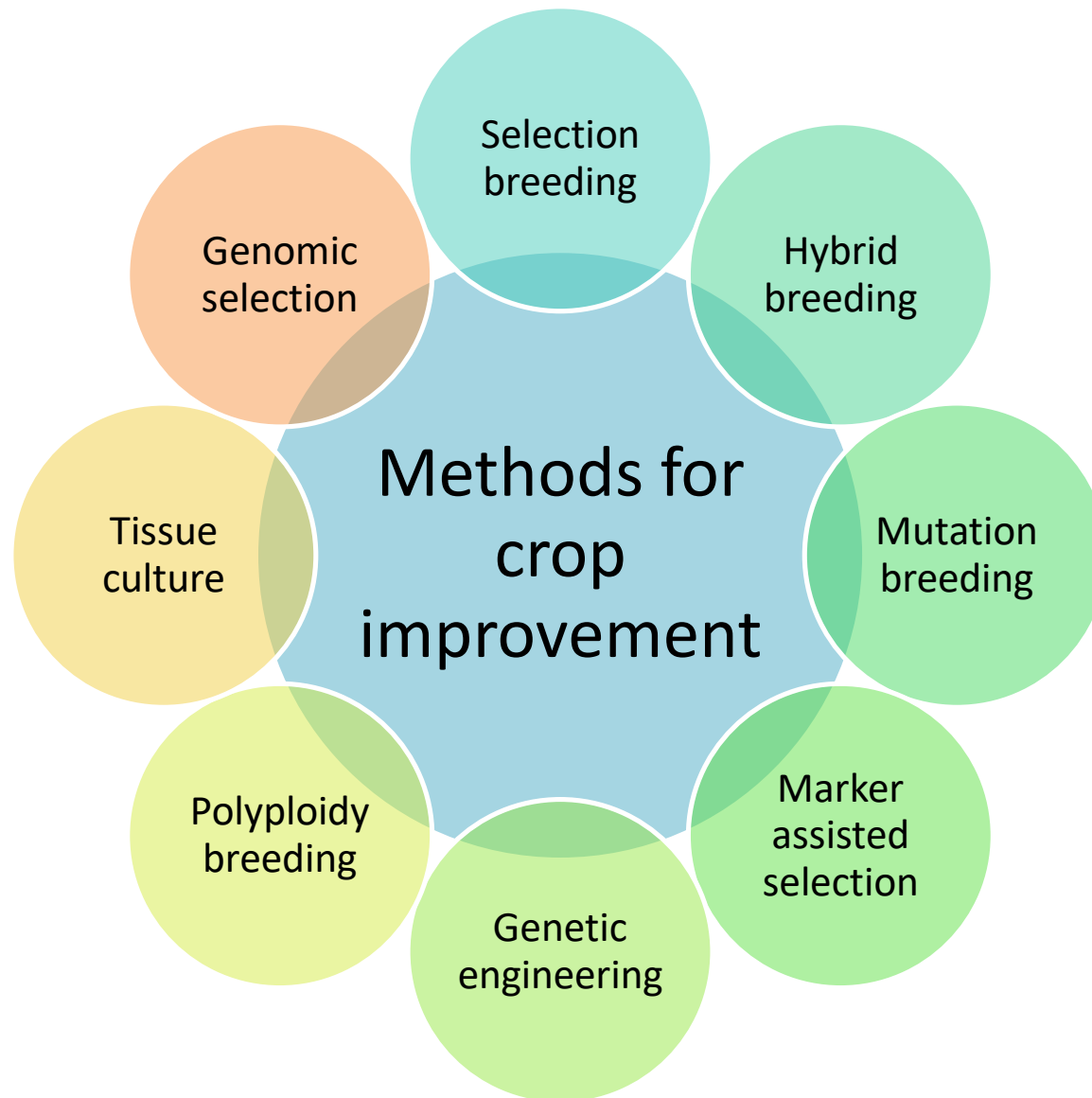
Genetic consequences of controlled pollination breeding:

- Predictable segregation
- Increased homozygosity
- Reduced genetic diversity

Application in plant breeding:

- Hybrid breeding
- Variety development
- Gene introgression

Methods of crop improvement



Selection breeding

A) In self pollinated crops:

- ***Selection permits reproduction only in those plants that have a desirable characteristics***
- ***Achieved by raising the next generation from seeds produced by the selected plants only***

Selection criteria:

- Based on phenotype of plants

Characteristics:

- Selection is effective for heritable differences only. Its effectiveness is greatly affected by heritability of the character under selection
- Selection does not create new variation. It only utilizes the variation already present in a population
- **Pureline-** is a progeny of a single, homozygous, self pollinated plant. All plants within a pureline have the same genotype
- The variation among purelines has a genetic component
- Genetic variation within a pureline may arise by mechanical mixture, natural hybridization, chromosomal aberrations and gene mutations

Requirements of selection:

- Variation must be present in the population
- Variation must be heritable
- Purpose of selection:
- To isolate desirable plant types from the population

Selection breeding

B) In cross pollinated crops:

Significance:

- Able to change the gene and genotype frequencies
- Able to produce new genotypes due to changed gene frequencies
- Able to Cause a shift in mean in the direction of selection
- Able to change the variance of population to some extent

Characteristics:

- Changes the mean in the direction of selection
- Increases the frequency of desirable alleles and genotypes
- Leads to production of new genotypes
- May or may not reduce genetic variance

Example for Selection

Hybrid breeding

Breeding which involves mating/ crossing of 2 plants or lines of dissimilar genotype

Characteristics:

- In plants, crossing is done by placing pollen grains from one genotype, the male parent, on to the stigma of flowers of the other genotype, the female parent
- The seeds as well as progeny resulting from the hybridization are known as hybrid or F1

Procedure and requirements:

- **Choice of parents-** Parents should be well adapted and proven variety in the area
- **Evaluation of parents-** Parents should be evaluated for their characters and qualities
- **Emasculation-** Removal of stamens or anthers or the killing of pollen grains of a flower without affecting in any way the female reproductive organs
- **Bagging-** Enclosing emasculated flowers in suitable bags of appropriate size to prevent random cross pollination
- **Tagging-** To note down the details of crossing and information related to the breeding programme
- **Pollination** – Collecting pollen from freshly dehiscent anthers of male parent and dusting this pollen on the stigma of emasculated flowers
- **Harvesting and storage of F1 seeds-** crossed heads/ pods should be harvested, threshed, stored to avoid contamination

Types:

- Intervarietal/ intraspecific hybridization- 2 parents involved in a cross belong to same variety, different varieties of same species
- Distant hybridization- 2 parents belonging to different species of same genus/ to different genera

Mutation breeding

Mutation- sudden heritable changes in a characteristic of an organism. It is a result of change in a gene, a change in chromosome that involves several genes or a change in plasma gene (genes present in cytoplasm eg, in chloroplast, mitochondria)

Utilization of induced mutations for crop improvement is known as mutation breeding

Characteristics:

- Induced mutations rarely produce new alleles
- They produce alleles which are already known to occur spontaneously
- Mutations are generally recessive but dominant mutations also occur
- Mutations are generally harmful to organisms
- Mutations are random
- Mutations are recurrent
- Induced mutations commonly show pleiotropy often due to mutations in closely linked genes

Procedure:

- Selection of the variety for mutagen treatment
- Selection of part of plant to be treated
- Dose of mutagen
- Giving the mutagen treatment
- Handling of the mutagen- treatment population

MAS

Technique used in plant breeding to select plants with desirable traits based on genetic markers

It involves identifying genetic markers linked to specific traits and using these markers to select plants with those traits

Characteristics:

- MAS accelerates breeding programs by reducing the need for phenotypic selection
- Allows for precise selection of plants with desired traits
- Reduces the time and resources required for breeding programmes

Procedure:

- Genetic markers are identified (Eg, SNPs, SSRs) associated with desired traits
- Analyzing plant DNA to determine the presence of these markers
- Selection of plant with desired markers and breed them to produce offspring with the desired traits

Types of Markers:

- Morphological markers- visible traits like plant height or flower color
- Biochemical markers- proteins or other molecules that can be used to identify specific traits
- Molecular markers- DNA based markers like SNPs, SSRs, AFLPs

Genetic engineering

It involves direct manipulation of plant's gene to introduce desirable traits. It is used to develop crops with improved yields, disease resistance and nutritional content

Characteristics:

It improves crop yields and productivity

It can introduce disease resistant genes

It reduces need for pesticides

Procedure:

Identification of genes that confer desirable traits

Isolating the identified genes from the source

Inserting the isolated genes into the target plant's genome

Introducing modified genes into plant cells

Selecting plants with desired traits

The chromosome number of an organism is an exact multiple of the basic or genomic number

When all genomes present in a polyploid species are identical, it is known as autopolyploid

If 2 or more distinct genomes are present, it is known as allopolyploid

Origin and production:

- Spontaneous mutation
- Triploid plants
- Asynaptic and desynaptic plants
- Translocation heterozygotes
- Tetrasomic plants

Characteristics:

- Polyploids have larger cell size than diploids
- Pollen grains of Polyploids are generally larger than those of corresponding diploids
- Polyploids generally slower in growth and later in flowering
- Polyploids usually have larger and thicker leaves, larger flowers and fruits
- Polyploids generally show reduced fertility due to irregularities during meiosis

Application of polyploidy in crop improvement:

- Used to develop homozygous diploid lines following chromosome doubling in 2 years
- Useful in the isolation of mutants
- Seedless watermelons production
- Triploid sugar beets
- Tetraploid maize (superior in quality)
- To overcome self incompatibility
- Utilizing as a bridging species
- Creation of new crop species (Triticale)

Polyploidy breeding

Tissue culture breeding

It involves growing plant cells or tissues in a controlled laboratory setting to produce new plants

Characteristics:

- Micropropagation- Allows for rapid multiplication of plants
- Sterile conditions- plant tissues are grown in sterile conditions to prevent contamination
- Controlled environment- temperature, light and nutrient levels are controlled to optimize growth

Applications in crop improvement:

- Embryo rescue- it allows for the rescue of embryos from incompatible crosses, enabling breeders to combine desirable traits from different species
- Overcoming reproductive barriers-It helps in expanding the gene pool for crop improvement through crossing plant varieties by overcoming their reproductive barriers
- Haploid production- It can produce double haploids, which are valuable for breeding purposes, enabling rapid development of homozygous lines
- Breeding efficiency- haploid production accelerates breeding programs by reducing the time required to produce homozygous lines
- Somatic hybridization- It enables fusion of protoplasts from different species, creating new hybrids with desirable traits
- It helps in expanding the genetic diversity of crops
- Genetic transformation- It can be used to introduce desirable genes into crops, improving traits such as disease resistance, drought tolerance and nutritional content
- Precision breeding- it enables breeders to introduce specific genes without altering the crop's genetic background

Genetic selection breeding

It involves selecting plants with desirable traits based on their genetic makeup

This approach is used to improve crop yields, disease resistance and nutritional contents

Characteristics:

- Genetic variation- it relies on existing genetic variation within a population
- Selection pressure- Breeders apply selection pressure to identify plants with desirable traits
- Genetic markers- Genetic markers can be used to identify plants with desirable traits

Application in crop improvement:

- Improved trait expression
- Increased genetic gain
- Crop improvement
- Increases efficiency breeding programmes